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THE PERFORMANCES OF THE ANTENNAS IN ACTIVE/PASSIVE COMPOUNDED GUIDANCE PART II: COMPOUNDED ANTENNAS SCHEMES AND PERFORMANCES OF ACTIVE/PASSIVE GUIDANCE

Hong Ma and Xining Shen

Department of Electronic and Information Engineering
Huazhong University of Science and Technology
Wuhan, Hubei, 430074
People's Republic of China

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Abstract — The second part of a two-part paper discusses two kinds common-caliber compound antennas techniques for active/passive guiding system. One is the triple-antenna compound technique which two spiral antennas are utilized to find the direction of a radiative source in passive amplitude-phase monopulse subsystem and the other is used in pulse-radar. The next is the double-antenna technique which one antenna is for passive amplitude-monopulse direction-finding and the another is for pulse-radar. The mutual influence among these antennas is analysed in details and the better one in the scheme is pointed out finally in this paper.

Key words : common-caliber compound antenna, mutual influence among antennas, active/passive guidance

I Introduction

In the first part of this paper, the performances of the spiral antennas and the direction-finding techniques in broadband passive guidance are deeply studied. In order to enhance the attacking power and increase the surveying distance of guided weapons, we can add an active pulse radar besides a passive direction-finding system.

These active/passive guided missiles are very useful for dealing with the target radars that are in the non-operating states and the other important targets that radiate little or none energy. Especially, the missiles can also attack target radars from the regions of their back-lobes or wide-angle side-lobes in a long distance.

The antenna of the active pulse-radar is required to possess higher gain, lower side-lobe-level, mechanical scanning, and be convenient to be compounded with the antennas of passive direction-finding system. The whole compounded antennas are suitable for installed in missile.

The usual parabolic antenna and cut-parabolic antenna are chosen to be the antennas of the active radar in this paper.

II The Performance of Triple-antenna Common-caliber Scheme

In the scheme, two two-arm spiral antennas (Archimedean spiral or equiangular spiral) are used in passive direction-finding system, and the amplitude-phase monopulse method is utilized to find the direction of radiative source on one plane (horizontal plane or vertical plane)[1] . The active radar antenna is a usual circular caliber parabolic antenna or a symmetric cut-parabolic antenna. The spiral antennas are placed by two sides of the parabolic reflector, and the included angle of these two inclinedly arranged spiral planes is $2\theta_0$ as shown in figure 1.

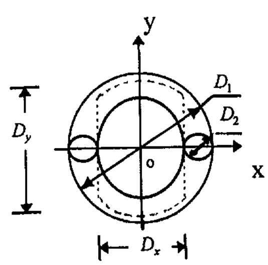

Fig.1 The antennas arrangement of triple-antenna compound scheme (D_1 : the compound caliber, D_2 : the spiral diameter)

A. The Analysis of Active Radar Antenna

In figure 1, the size of the parabolic reflector is,

$D_x = D_y = D_1 - 2D_2$ (for the circular-caliber parabolic surface)

$D_x = D_1 - 2D_2, D_y = D_1$ (for the symmetric cut-parabolic surface)

The far-field patterns and gains of the above parabolic antennas are shown in figure 2,3,4, where the forward feeding-sources are all standard rectangular waveguide. It is well known that the cross-polarization level of the cut-parabolic antenna is higher than that of the standard one.

B. The Received Leaking-power by Spiral Antennas Radiating from Parabolic Antenna

Because the spiral antennas are placed by the sides of the parabolic reflector, they will definitely receive some bigger power radiating from the feeding-source of the parabolic antenna when the operating frequency of the feeding-source is in the region of the effective frequency-band of the spirals. Assuming both of the spiral antennas far enough away the feeding-source, they receive the leaking-power as,

$$P_r = \left[\frac{\lambda}{2\pi(D_1 - D_2)} F(\xi_1, 0)\sin\xi_1\right]^2 G_0 G(\xi_1 + \theta_0, 0) P_t$$

where, λ is the wavelength of the active radar, P_t is its transmitting power. $F(\xi_1, 0)$ is the normalized field-strength direction function of the feeding-source along the direction $(\xi_1, 0)$, G_0 is the power gain along the maximum radiative direction. $G(\xi_1 + \theta_0, 0)$ is the power gain of the spiral antenna along the direction $(\xi_1 + \theta_0, 0)$, and ξ_1 is decided by,

$$\xi_1 = tg^{-1}\left[\frac{1+\cos\xi_0}{4f\cos\xi_0}(D_1 - D_2)\right]$$

here, f is the focus-length of the parabolic surface, ξ_0 is its caliber field-angle.

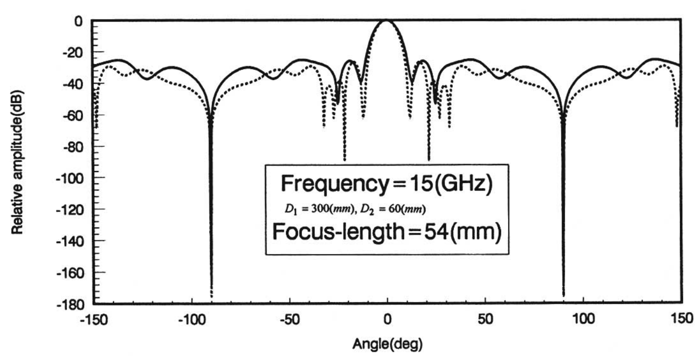

Fig.2 The amplitude pattern on horizontal plane
(—: circular caliber, ...: cut caliber)

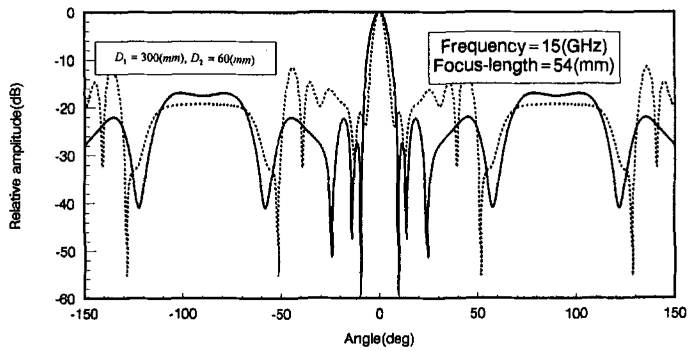

Fig.3 The amplitude pattern on vertical plane
(—: circular caliber, ...: cut caliber)

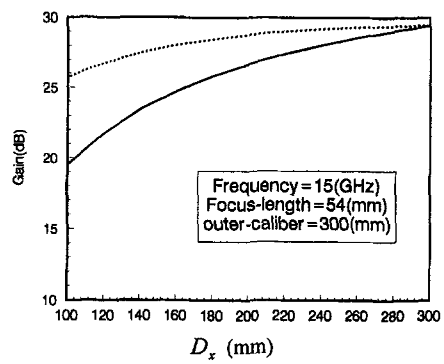

Fig.4 The antenna's gain vs. D_x
(—: circular caliber, ...: cut caliber, and $D_1 = 300mm$)

Changing the distance between the caliber-centers of the active and passive antennas, namely L, will also change the leaking-power P_r as shown in figure 5, where the parameters are $D_1 = 300mm, f = 54mm, \lambda = 20mm, P_t = 60kW$, and the Archimedean spiral constant is 0.47746mm, the diameter of the spiral is 60mm.

The curves suggest that the bigger receiving power should be completely absorbed,

otherwise it may puncture the front-end circuits of the passive direction-finding system that is high sensitive. Simultaneously, we must pay attention to the fact that the power may also worsen the far-field characteristic of the parabolic antenna of the active radar (widen the main-lobe and raise the side-lobe-level) if it is directly reflected to the caliber plane of the spiral antenna. A few PIN diodes to compose a switch can be linked among the output ports of the spiral antenna and the input port of the passive receiver to avoid the above situations, shown in figure 6. The transmitting pulse of the active radar is used as the synchronizing signal to control the PIN switch to induct the received leaking-power to the matching-load at the transmitting phase of the active radar and to connect the spiral antenna with the front-end at the transmitting intermittent phase. The frequency-band of the switch is required as wide as that of the spiral antenna.

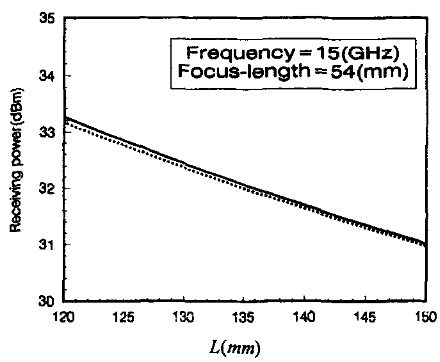

Fig.5 The received leaking-power changing with the distance of the two caliber-centers (—: $\theta_0 = 0^0$, ...: $\theta_0 = 10^0$)

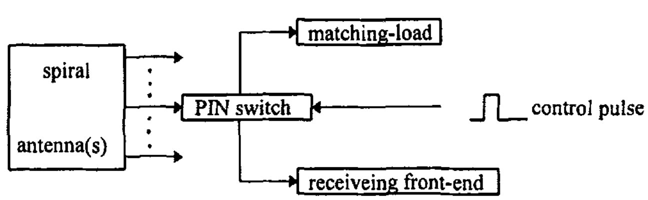

Fig.6 The circuit to avoid puncturing the front-end and worsening the radiative field of the parabolic antenna

C. The Scattered Waves by the Spiral Planes

A mostly part of the energy irradiating the spiral planes from the rectangular waveguide feeding-source of the parabolic antenna enters the inner of the spiral antennas to be absorbed shown as the above, the remains is directly scattered to the original space by the spiral planes. The second part will cause some new wide-angular side-lobes on the horizontal plane (or the vertical plane) of the far-field of the parabolic antenna. After considering a proper equivalent reflecting coefficient η, we can approximately regard the spiral planes as conducting planes. So the scattering effects of the planes for the incident waves from the feeding-source can be obtained by first evaluating the caliber-field on the planes and then getting the far-field. Noting the not in-phase distribution of the caliber-field, the scattered far-field must be obtained by the general Kirchhoff Formula[2] as,

$$E_\theta = -j\frac{\beta e^{-j\beta r}}{4\pi r}\int_0^{2\pi}\int_0^{c}\left[A_1\sin\Phi - A_2\cos\Phi\right]e^{j\beta\rho'\sin\theta\cos(\Phi''-\Phi)}\rho' d\rho' d\Phi''$$

$$E_\Phi = -j\frac{\beta e^{-j\beta r}}{4\pi r}\int_0^{2\pi}\int_0^{c}\left[A_1\cos\theta\cos\Phi - A_2\cos\theta\sin\Phi + A_3\sin\theta\right]e^{j\beta\rho'\sin\theta\cos(\Phi''-\Phi)}\rho' d\rho' d\Phi''$$

where,

$$A_1 = \left[d_3\cos\theta\sin\xi\sin\Phi' - d_2\cos\theta\cos\xi - d_2\right]A(\rho,\xi,\Phi')$$

$$A_2 = \left[d_1\cos\theta\cos\xi - d_3\cos\theta\sin\xi\cos\Phi' + d_1\right]A(\rho,\xi,\Phi')$$

$$A_3 = \left[d_1\sin\theta\cos\xi\sin\Phi - d_2\sin\theta\cos\Phi\cos\xi + d_3\sin\theta\sin\xi\sin(\Phi' - \Phi)\right]A(\rho,\xi,\Phi')$$

$$A(\rho,\xi,\Phi') = \eta\left[\sqrt{\frac{\mu_0}{\varepsilon_0}}\frac{G_0P_t}{4\pi}\right]^{\frac{1}{2}}\frac{F(\xi,\Phi')}{\rho}\sin\xi e^{-j\beta\frac{\rho}{\sin\xi}}$$

$$d_1 = \sqrt{1-\sin^2\xi\cos^2\Phi'}, \quad d_2 = -\frac{\sin^2\xi\sin 2\Phi'}{2\sqrt{1-\sin^2\xi\cos^2\Phi'}}, \quad d_3 = \frac{\sin 2\xi\cos\Phi'}{2\sqrt{1-\sin^2\xi\cos^2\Phi'}}$$

$$\rho = \sqrt{\rho'^2 + l^2 + 2\rho' l\cos\Phi''}, \quad \xi = tg^{-1}\left[\frac{1+\cos\xi_0}{2f\cos\xi_0}\rho\right], \quad \Phi' = tg^{-1}\left[\frac{\rho'\sin\Phi''}{l+\rho'\cos\Phi''}\right]$$

$$0 \le \rho' \le c, \qquad 0 \le \Phi'' \le 2\pi$$

where c is the radius of the spiral plane, l is the distance between two caliber-centers of the active and passive antennas . Figure 7 shows the scattering field of the left and right spiral planes on the direction-finding plane (horizontal plane) of the passive monopulse system. Though two obvious side-lobes arise at about $\pm 119^\circ$, they may not influence the normal operation of the whole system because of the relatively lower levels and relatively far from the boresight axis.

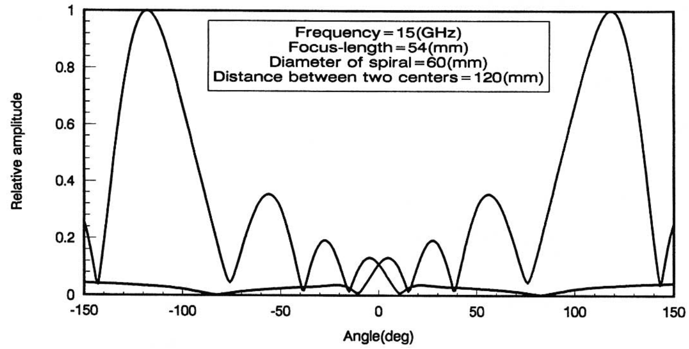

Fig.7 The scattering far-field of the two spiral planes

III The Performance of Double-antenna Common-caliber Scheme

In this scheme, one two-arm equiangular spiral antenna is connected with the operating-network[1,3] in passive direction-finding system to form two overlapping beams, and the amplitude-amplitude monopulse technique is utilized to find the direction of a radiative source on one plane[1] . The active radar antenna is a usual circular-caliber parabolic antenna or a nonsymmetric cut-parabolic antenna. The spiral antenna is placed by the right side (or the left side) of the parabolic reflector, as shown in figure 8.

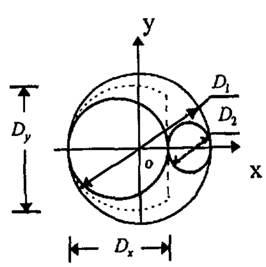

Fig.8 The antenna-arrangement of double-antenna compound scheme
(D_1 : the compound caliber, D_2 : the spiral diameter)

The spiral constant has little effect on the measuring-angle range of the passive direction-finding system already shown in reference [1], so a smaller spiral constant (hereby, a smaller diameter of the spiral antenna) can be selected to leave a relatively wider space for the parabolic reflector.

A. The Analysis of Active Radar Antenna

In figure 8, the size of the parabolic reflector is,

$D_x = D_y = D_1 - D_2$ (for the circular-caliber parabolic surface)

$D_x = D_1 - D_2, D_y = D_1$ (for the nonsymmetric cut-parabolic surface)

Table 1 shows the characteristics of far-field patterns and gain of the above antennas. Here, the frequency is 15GHz, D_1 is 300mm, D_2 is 60mm, the focus-length is 80mm.

Table 1 The computation results of the performances of the double-antenna common-caliber compound scheme

	$2\theta_{0.5}$(deg) ($\Phi = 0^0$)	$2\theta_{0.5}$(deg) ($\Phi = 90^0$)	$SLL(dB)$ ($\Phi = 0^0$)	$SLL(dB)$ ($\Phi = 90^0$)	$Gain(dB)$	$P_r(dBm)$
Circular-caliber parabolic antenna	5.95	5.40	-25.8	-24.5	28.27	33.90
Nonsymmetric cut-parabolic antenna	5.74	4.35	-23.5	-22.6	29.52	27.80

B. The Received Leaking-power by the Spiral Antenna

In the scheme, the received leaking-power by the spiral antenna radiating from the feeding-source of the parabolic antenna is,

$$P_r = \begin{cases} \left[\dfrac{\lambda}{2\pi D_1} F(\xi_1, 0)\sin\xi_1\right]^2 G_0 G(\xi_1, 0) P_t \\ \left[\dfrac{\lambda}{2\pi (D_1 - D_2)} F(\xi_2, 0)\sin\xi_2\right]^2 G_0 G(\xi_2, 0) P_t \end{cases}$$

The first formula is for the circular caliber parabolic antenna, the next is for the nonsymmetric cut parabolic antenna, where

$$\xi_1 = tg^{-1}\left(\frac{1+\cos\xi_{01}}{4f\cos\xi_{01}} D_1\right), \qquad \xi_{01} = 2tg^{-1}\left(\frac{D_1 - D_2}{4f}\right)$$

$$\xi_2 = tg^{-1}\left(\frac{1+\cos\xi_{02}}{4f\cos\xi_{02}} (D_1 - D_2)\right), \qquad \xi_{02} = 2tg^{-1}\left(\frac{D_1}{4f}\right)$$

$G(\xi_1,0)$ is the power-gain of the equiangular spiral antenna along the direction $(\xi_1,0)$. Because the output signals of the beam-operating network are the linear combination of M_1 mode and M_2 mode of the spiral antenna, $G(\xi_1,0)$ should be

$$G(\xi_1,0) = G_1(\xi_1,0) + G_2(\xi_1,0)$$

where G_1 and G_2 are the gains of M_1 mode and M_2 mode separately. $G(\xi_2,0)$ can also be found by the same way. The computation results are also shown in Table 1.

C. The Scattered Wave by the Spiral Plane

Because of only one spiral antenna existing by the side of the parabolic reflector, the scattered wave by the spiral plane is not symmetric in figure 9. It is seen that a wide-angle side-lobe also appears.

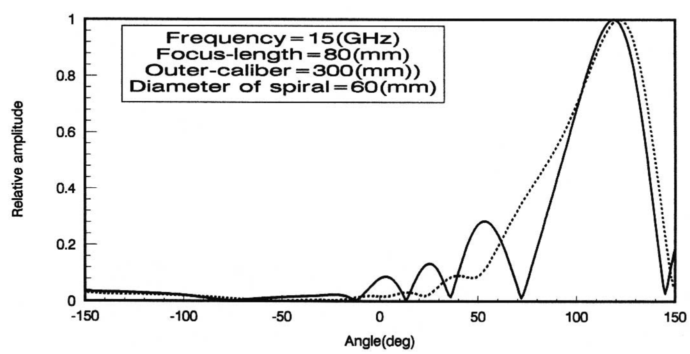

Fig.9 The scattering far-field of one spiral plane on the horizontal plane
— : circular caliber, ... : cut caliber

IV Conclusion

Two kinds of common-caliber arranged-antennas schemes for the active/passive compounded guidance are raised in the paper. According to the computation results, the first scheme is better than the latter, and it gives consideration to both complication and performance of the whole active/passive system.

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